# FINAL REPORT
## Appendix Volume 1 (Appendices I-II)
## SERDP PROJECT CS-1100



**MODELING THE EFFECTS OF ECOSYSTEM FRAGMENTATION AND RESTORATION: MANAGEMENT MODELS FOR MOBILE ANIMALS**
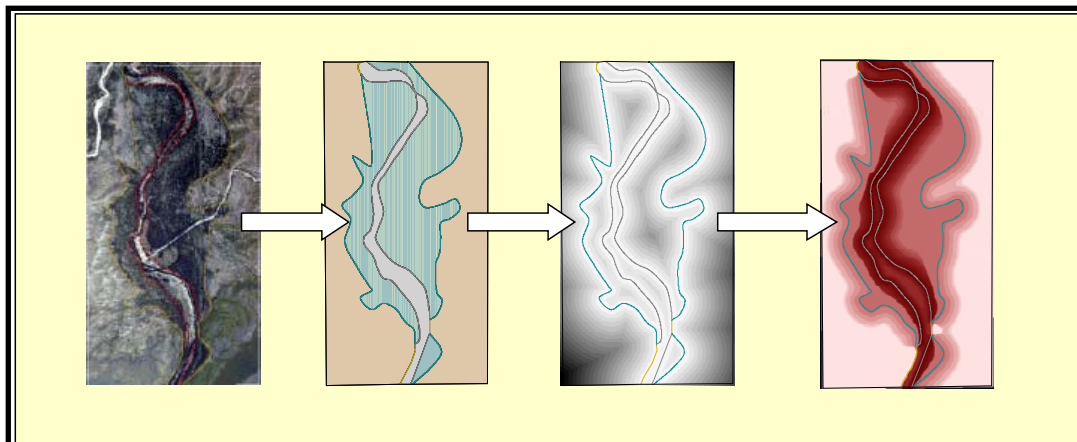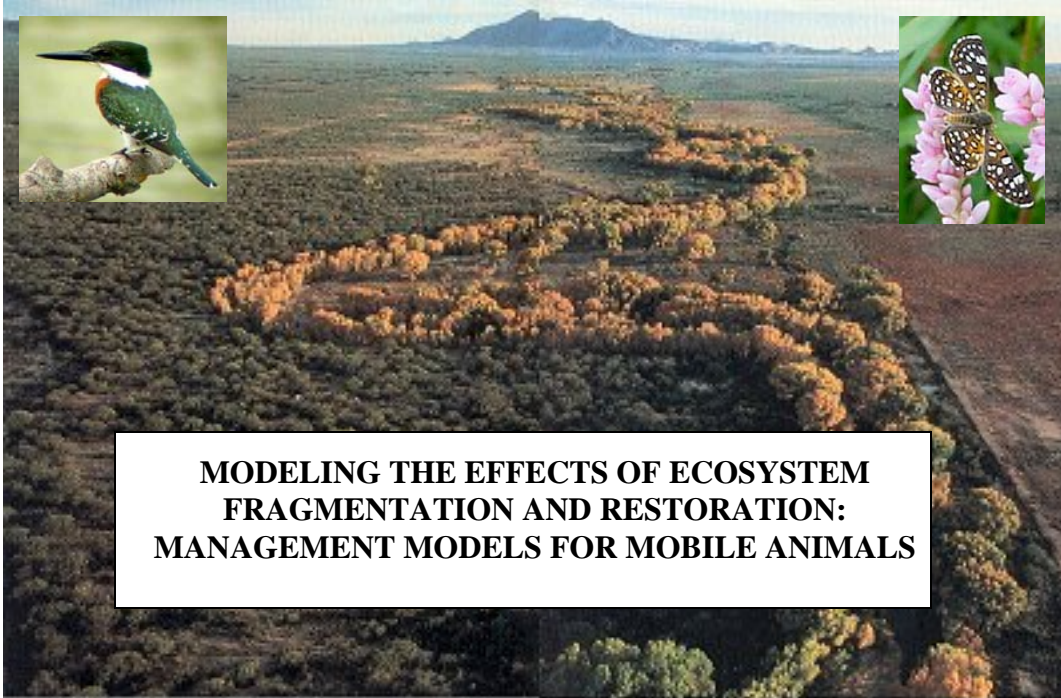


**1 DECEMBER 2003**

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# CONTENTS

# Effective Area Model (EAM)
**Version 1Beta**

# User Guide

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**TABLE OF CONTENTS**

# Background

The detrimental effects of habitat fragmentation on animal populations are widely documented (Whitcomb et al. 1981, Robinson et al. 1995), however, the development of practical tools to predict the effects of fragmentation and design appropriate mitigation efforts has progressed slowly (Saunders et al 1991, Wiens 1995).  The Effective Area Model (EAM) is designed to provide a predictive tool to link field and remotely sensed data in a landscape model that permits comparison of the impacts of alternative land use strategies on animal populations (Sisk and Margules 1993, Sisk et al. 1997).  The model uses quantitative measures of species-specific edge effects to weight habitat quality within a particular patch, based on distance from the edge.  The model then generates predictions of the distributions of organisms, resources, or environmental conditions in heterogeneous landscapes.

The EAM provides an interface that allows users to easily calculate animal density or other landscape-scale variables given user-supplied edge response functions and habitat spatial data.  The EAM is an extension to ArcView GIS v3.x (ESRI, Redlands, California) and is written in Avenue, an ArcView scripting language.  The instructions presented in this manual assume you have a basic understanding of the use of geographic data and ArcView GIS.

# Instructions for Beta Testers

This is the first beta release of the EAM and is intended for error-checking and eliciting comments for improving or clarifying the use of the model or this user manual.  The final release of the model is planned for Fall 2001.  Please send your questions, comments, and findings of errors to Haydee.Hampton@NAU.edu with any files that would help to reproduce or demonstrate any errors, such as, habitat data or output from the model.  If files are too large to email they can be sent via anonymous FTP to vishnu.glg.nau.edu /pub/incoming/EAM.  It would be helpful for debugging model errors if you would supply the following information about your computer set up and input data: 1) format of habitat spatial data (polygon shapefile or Arc/Info grid) 2) version of ArcView GIS, 3) version of Spatial Analyst, 4) operating system (Windows95, 98, or NT), and 5) the use of Import or Import71 to import an Arc/Info export format file (.e00) into Arc/Info or ArcView GIS.  A prioritized list of suggested model modifications or additions would also be helpful in planning future modeling efforts.

# System Requirements

### Hardware

Because of the size of habitat spatial data sets and the complexity of the calculations to generate some output, we recommend a minimum of a Pentium II 266 MHz (or equivalent) with 32 MB of memory. A preferred system would be a Pentium II 400MHz (or equivalent) with 64MB of memory and a fast (<8 ms) hard drive or better.

### Software

To use the EAM, you will need ArcView GIS 3.1 or 3.2 and the Spatial Analyst extension. The Windows (95, 98 and NT) environment is supported.

# Installation

To load the extension, copy the eam_.avx (e.g., eam1beta.avx) file to your extensions directory. Windows defaults to the ArcView install directory (C:\ESRI\AV_GIS30\ARCVIEW\EXT32). If not already present, copy the file avdlog.dll to the bin32 directory and avdlog.dat to the lib32 directory of the ArcView install directory.

After opening ArcView, make the Project window active, go to the File menu, click on Extensions, and check the Effective Area Model option. This will add a new menu ("EAM") to the View graphical user interface (GUI) (Figure 1).

Figure 1. EAM menu in View GUI menu bar.
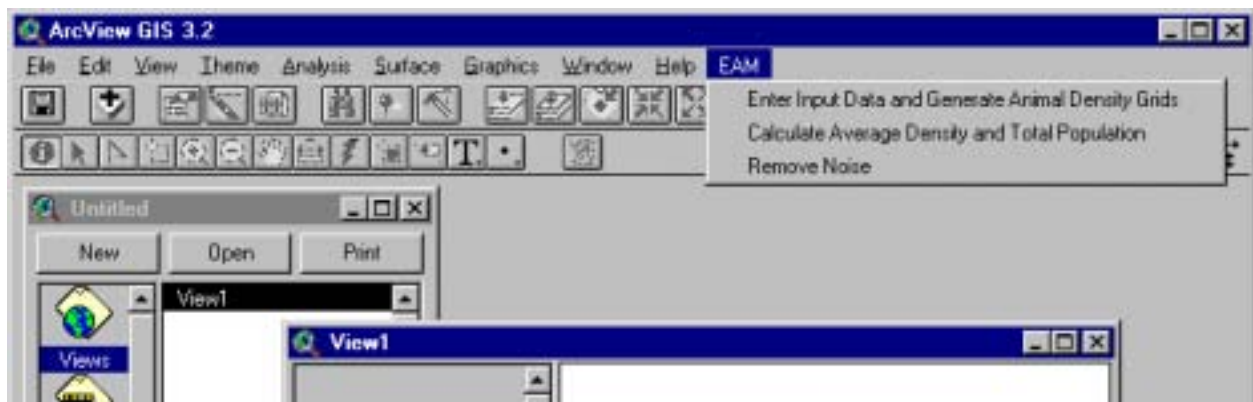


# Data Requirements

The EAM requires habitat spatial data and functions describing the change in animal density (or another response variable) with distance from edge. For example, a response function may describe the change in the density of a certain species of butterfly with distance from the boundary between a grassland and forest boundary. The extension generates output themes in the same projection and horizontal datum[1], with the same map units[2], as the habitat theme. It is

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[1] If the View has not been projected, the model assumes the features are already in the desired map projection. For example, if the habitat theme is in UTM zone 12, NAD27, then the output grids generated will also be in this projection and datum. If the View has been projected then the model output will be in this projection/datum. A View's map projection can only be set if the map units of the spatial data it

important that you know the map units of your data, because the distance values of the animal density response function must be in the same units.  Vector themes must be in ArcView GIS shapefile format.  Raster themes must be in Arc/Info GRID format.

### *Habitat Spatial Data*

The habitat map input by the user should contain the appropriate habitat classes for the species to be modeled.   Optimally, it should describe all variation in the habitat that a species responds to, in terms of floristics (i.e., vegetation species or class), vegetation structure (e.g., density or height), and perhaps other landscape variables, such as, elevation (e.g., lowland mesquite or highland mesquite). In reality, the information on animal density in every habitat will likely be limited, so only the different habitats for which the user has density data need be contained in the initial habitat map.  The model will partition the habitat map into regions representing edge type, such as locations within mesquite approaching cottonwood.  The user has the option of inputting edge response fuctions for these habitat boundaries or simply allowing the model to use the interior edge type for each habitat patch, regardless of the type and proximity of adjacent habitat.

The habitat spatial data must be a projected integer grid or polygon shapefile theme.  If the habitat theme is unprojected, that is, if it's in geographic (longitude-latitude) coordinates, project it before running the EAM.  Shapefiles can be projected using ESRI's Projection utility distributed with ArcView 3.2 and likely subsequent versions.  If using non-grid data, there must be a field in the theme's feature attribute table representing habitat classes and the user will be prompted to specify the cell size of the output grids.  The model will accept any value, although you should use an appropriate level given the resolution of your habitat data and response functions.

Possible sources of digital habitat spatial data are state Gap Analysis Programs (GAPs), state land departments and state universities.

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contains (or will contain) are decimal degrees (i.e., degrees of longitude-latitude expressed as a decimal rather than in degrees, minutes and seconds) (ESRI, ArcView 3.2 Help).
[2] Map units are the units of the View's display surface. A View is an ArcView document that provides a means to display and query spatial data.  If the View has not been projected, Map units are the units in which the coordinates of the spatial data contained in the View are stored.  However, in this case you must manually specify the map units in the "View Properties" dialog, which can be opened from the View menu, Properties menu item.  If the View has been projected, Map units are the units into which this data is being projected in the View (ESRI, ArcView 3.2 Help).

### *Response Functions*

The user may input either linear (Figure 2) or non-linear animal response functions. Note that distance to edge is the only predictor variable used in these equations. To input linear functions, the user enters the animal density at the edge and the interior habitat for each edge type found in the habitat theme (the model then calculates the slope of the linear function). Edge types are defined by an interior habitat type and the closest neighboring habitat (e.g., in grass approaching cottonwood). The distance value units of the animal density response functions must be the same units as the map units of the habitat theme. For example, if the habitat theme's map units are in meters, then the units of the distance to habitat boundary (independent) variable are assumed to be in meters.

Figure 2. Sample density response functions for a butterfly species in southern Arizona.
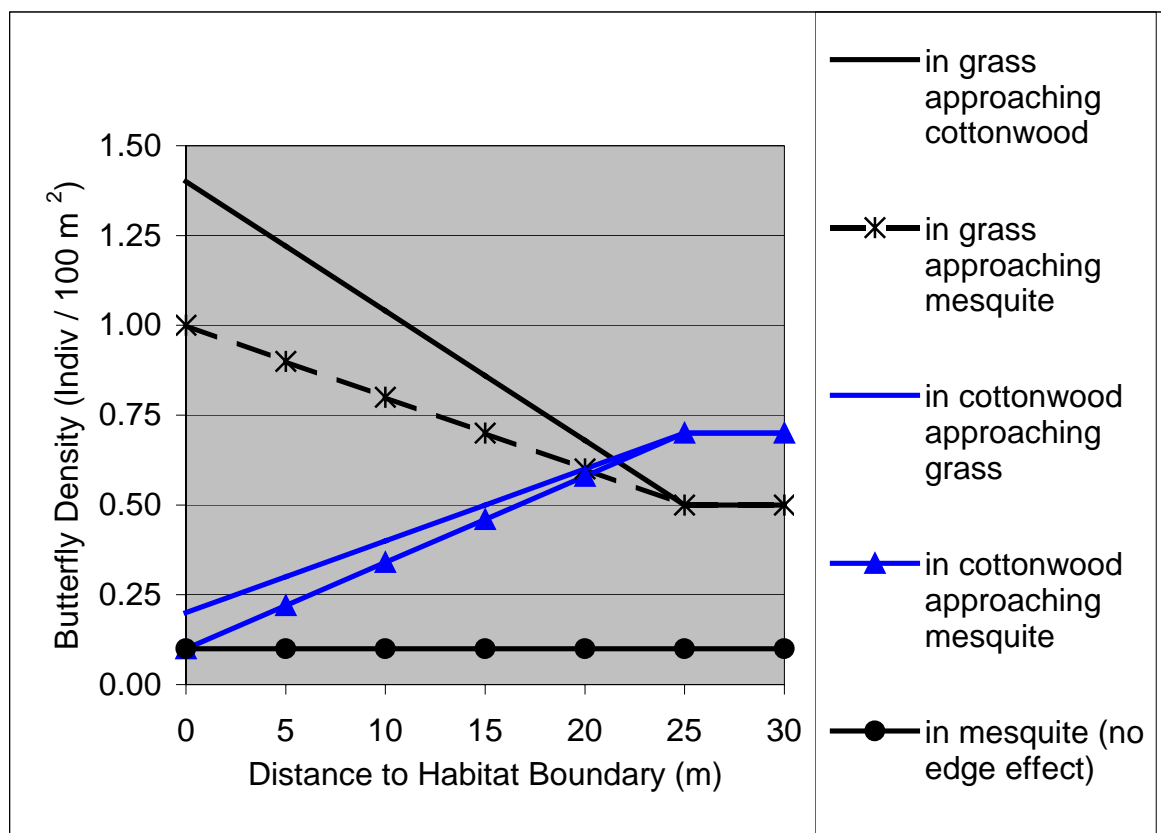


## How to Run the Model

Open an existing or new ArcView GIS project. Open a View, and if not already present, add at least one ArcView polygon shapefile or ARC/INFO grid containing habitat spatial data. Specify the map units of the habitat theme in the View menu under Properties. Set the project's Working Directory to the directory where you would like to store model outputs, such as, grids and database files.[3]

The EAM currently adds three menu items to the View GUI's menu bar: "Enter Input Data and

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[3] "The project's working directory defaults to $HOME. You can change the working directory for your project either through the project's property dialog box or through the Set Working Directory choice in the View document user interface File menu" (ArcView v3.2 help documentation).

Generate Animal Density Grids", "Calculate Average Density and Total Population" and "Remove Noise."

### *Menu Item 1: Enter Input Data and Generate Animal Density Grids*

The first menu item in the EAM menu opens the "Effective Area Model: Data Input and Output Grid Generator" dialog box (Figure 3). After choosing this menu item, select one of the habitat themes that you placed in the View, which can be found in the "Habitat theme" drop-down menu near the top of the dialog box. If the theme is a polygon shapefile, then click on the field in the "Habitat theme field" drop-down menu that contains habitat classes. These classes will be used to define the edge types in your habitat data. The "Habitat theme field" will be dimmed and unavailable if the habitat theme is based on a grid. In this case, the model uses the grid's integer values as habitat classes.[4]

Type a run name in the "Run name" text box at the top of the dialog box. Use either a name made up of only one word or multiple words connected by underlines. The "Edge grid" drop-down menu should contain the line "none-create from habitat theme".

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[4] If an S_Value field is present in the habitat grid's value attribute table (VAT), its habitat classes will be used to name the edge types. The model creates the S_Value field when it converts polygon shapefiles to grids. It contains the user-selected habitat field from the initial shapefile.

Figure 3. EAM dialog box for entering input data and generating animal density grids.



## Determine Habitat Edges

Hit the "Find habitat edges" button in the top right of the dialog box. If the habitat theme is a polygon shapefile, you will be presented with a dialog box asking for the extent and cellsize of the output grid (Figure 4). Choose options suitable for the current study and input data and hit "OK". In general, the cell size should be at least two or three times less than the lowest dmax[5] value in order to capture the change in density values across habitat edges (assuming linear density functions are used). To model the entire habitat theme, select "Same as *<the name of the habitat theme>*". To model a subset of the habitat theme, zoom in to an area in the View window and select "Same as Display".

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[5] Dmax is a variable representing the extent of edge influence for any one animal density response function. For example, the edge response of a certain bird species may be restricted to a distance within 200 meters of mesquite habitat when approaching from scrubland.

Figure 4. Extent and Cell Size dialog box



After hitting "OK" (or after hitting "Find habitat edges," if your habitat theme is in GRID format), wait until the model completes its list of habitat edges in the Habitat Edges list box, which is the table in the center of the dialog. All fields will initially be filled with zeroes. The time it takes will depend on your computer setup, the total number of pixels in the habitat grid, and the number of habitat classes within the study area. The model runs faster with larger cell sizes and smaller extents (set in the "Extent and Cell Size of Output Grid" dialog box), because these both reduce the total number of pixels analyzed.

The source of the Habitat Edges list box is an edge grid that is added to the current View after the user clicks on the "Find habitat edges" button. The Edge grid represents the habitat edge types in your study area and its table can be edited either in a Table (an ArcView viewer for tabular data) or the Habitat Edges list box. A Distance grid is also added to the View containing distance values to the closest habitat edge. Hit the "Cancel" button to return to the View in order to find these two intermediate grids. To return to viewing the Habitat Edges list box, reopen the "Effective Area Model: Data Input and Output Grid Generator" dialog box and select the appropriate edge grid from the "edge grid" dropdown box. All output grid data sets are temporary and are deleted when their associated themes are deleted. Use Save Data Set in the Theme menu or save the project to prevent any grid data set from being deleted when the theme is deleted.

## Edge grid

The model creates the edge grid by finding the closest neighboring habitat to each cell and combining it with the initial habitat map. The animal density response functions input by the user are applied to the appropriate areas in proximity to habitat edges. If there is no edge response information for a specific edge type, you can specify an interior animal density to be applied to this edge area.

## Distance grid

The model uses the habitat spatial data to create a distance to edge grid by calculating for each cell the Euclidean distance to the closest cell of a neighboring habitat. To approximate the distance to the habitat boundary one-half the cell size is subtracted from this value. For example, a cell sharing a complete side with a cell of a differing habitat will have a distance to

edge of one-half its cell size (Euclidean distance to the closest cell of a neighboring habitat minus one-half cell size). This method slightly underestimates the distance to edge of cells that are not perpendicular to the closest cell of a neighboring habitat if the habitat boundary is considered to be the irregular raster boundary. Because the habitat boundary more likely follows a smoother path, this approximation probably neither over or under estimates the true distance to edge.

## Enter Input Data and Generate Animal Density Grids

The user has the choice of entering either linear or nonlinear animal density functions for each edge type.  If a nonlinear function is entered, it takes precedence over any linear input values (for edge and basal density) entered in the Habitat Edges table.

## Linear Animal Density Functions

In order to enter linear[6] animal density response functions, highlight any row in the Habitat Edges table by clicking on it once with your mouse.  Enter the density of the species on the edge of the habitat and adjacent habitat types (Hab_AdjHab column) in the selected row in the Habitat Edges text box.  For example, you would enter 0.2 in the EdgeDens column to model the density of the hypothetical butterfly in cottonwood habitat approaching mesquite (Figure 2). Hit the tab button, or use your mouse to move to the basal density column (BasalDens)[7] and extent of edge influence (dmax) values, which in the same example would be 0.7 and 25, respectively.  To model no edge effect (the null model) for any one edge type, enter a value of zero for dmax in the row labeled with the appropriate Hab_AdjHab class.

To enter linear animal density response functions[8] using a spreadsheet or database program, or to save a copy of the functions you have entered, hit the "Save response functions" button.  This will export your functions to a dBase file. You will be prompted to specify a filename and path. dBase III or IV formats are compatible with ArcView, so if you edit your functions database file outside of ArcView, save your edits in one of these formats.  It is also possible to load a previously saved dBase file by clicking on the "Load response functions" button, however the Hab_adjhab fields must be identical in the saved dBase file and the Habitat Edges table.  You can edit the saved dBase file, if they are not.  To change the label of subsequent animal density grids, change the run name in the first line of the dialog.

## Non-linear Animal Density Functions Calculator

To enter non-linear functions, double-click on a row in the Habitat Edges table.  The Nonlinear Animal Density Functions Calculator (Figure 5) will open allowing you to enter any equation permitted by ESRI's Spatial Analyst extension.  Clicking on the "dist, distance to edge" list box entry will place the variable "dist" in the "density =" box.  Use a combination of single clicking on the arithmetic function (+, -, *, /) and other buttons and double-clicking on the numerical requests to build an expression.  You can also type them in directly using keyboard strokes after moving the cursor to the "density = " box.  See "Entering formulas" in the "Trouble Shooting and Tips" section of this manual for a discussion of important ArcView formula formatting requirements.  These requirements are equivalent to those required to use ArcView GIS's "Map Calculator" found under the Analysis menu.  Hit "OK" to enter the formula for use in the EAM. Enter a dmax value in the Habitat Edges table.  The model will apply this dmax value to any

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[6] Linear is used here in the mathematical sense to describe equations of the form: $y = mx + b$.  All other equations are termed non-linear.
[7] Basal density is the density of the interior habitat.
[8] Non-linear functions must be added via the EAM "Calculator: Nonlinear Animal Density Functions" dialog.

formulas entered in the calculator.

Figure 5.  Nonlinear Animal Density Function Calculator
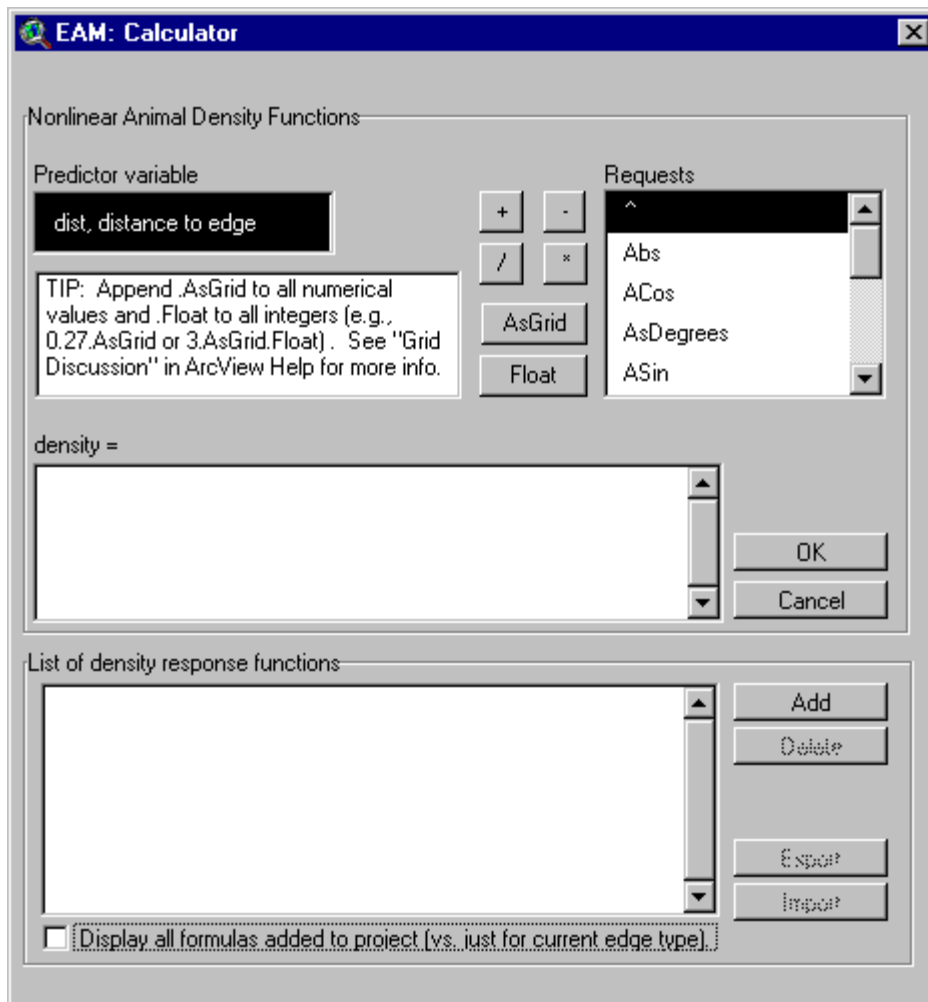


It is also possible to add the density equation to a list of equations stored with the current ArcView project with the "Add" button.  Highlight an equation in the list to delete it using the "Delete" button.  Click on the checkbox at the bottom of the Calculator to list all formulas that have been added to the current project.  Otherwise, only formulas added for the current edge type will be shown in the list.  You can export these formulas using the "Export" button and import previously saved formula lists (perhaps from another ArcView project) using the "Import" button.  The exported dBase file will contain a "CurrentEAM" field, indicating whether the formula was currently set for use in the model, or only added to the list of available equations.

## Estimate Empirical Error
The model uses the remaining five model parameters (n, dbar, Sxx, MSE, and tstat) in the Habitat Edges table only if the "Generate error grid using confidence interval (%)" text box is greater than zero.  The model uses these values to calculate the margin of error[9] for each pixel

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[9] The margin of error is the difference between the predicted value of animal density and the upper bound of the confidence interval set by the user.  Note that because the difference between the predicted value and the lower bound could be less than zero in some regions in the study area, care must be taken when

in the animal density grid using the standard confidence interval formula shown in equation 1 (Ott 1993). This formula does not apply to nonlinear equations, so these values should be set to zero for any edge type in which a nonlinear formula is applied.

One of the main assumptions underlying this equation is that the response variable (i.e., animal density) is normally distributed given any value of the predictor variable (i.e., distance from edge). Set the confidence limit, $(1-\propto)100\%$, to a specific value (e.g., 90%) to determine the margin of error in animal density at each pixel. The alpha you choose should also be used to select the appropriate t-value (tstat).

$$ME = t_{\alpha/2} \sqrt{MSE \left\{ \frac{1}{n} + \frac{\left( d - \bar{d} \right)^2}{\left[ \sum \left( d_i - \bar{d} \right)^2 \right]} \right\}} \tag{1}$$

where,

ME = margin of error (equivalent to one-half the confidence interval)

$t_{\alpha/2}$ = t-statistic from Student's t distribution for a two-tailed test. The t-value is based on df = n − 2 for linear equations of the form y = mx + b.

MSE = $\sqrt{(y - \hat{y})^2 / (df - 2)}$ , mean-squared error (for form y = mx+b).

n = total number of animal density observations at all distances from edge for one edge type used to develop animal density response function.

d = distance from edge

d-bar = average distance from edge of all observations used to develop animal density response function.

Sxx = $\sum \left( d_i - \bar{d} \right)^2$

Hit Enter on your keyboard and the density response function values you typed in should appear in the Habitat Edges table. Use your mouse to select the next row. The model assumes the units for dmax are the same as the map units of the habitat spatial data. For edge types in which no edge effect will be modeled, enter a "basal density" value and set "dmax" to zero. The edge density values will be ignored in this edge type, which is equivalent to the null model assumptions.

## Set Filters for Converging Habitats

When you have finished entering the animal density response functions, insert the filtering

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using the margin of error grid to calculate any descriptive statistics (e.g., the lower bound of a 90% confidence interval of total population in the study site).

distances of your choice in the two text boxes in "Apply a circular filter of radius __ to all pixels within __ m of three or more converging habitats" or accept the default values of zero.  This filtering option will smooth any abrupt changes in animal density values near converging habitat edges.

## Generate Animal Density Grids

To distribute the animal density functions across the habitat map, and to optionally create margin of error grids, click on the "Generate density grid" button near the bottom of the dialog box.  Ignore the "Choose an Effective Area Model (EAM) approach" button options, which are not enabled at this time.  The model defaults to the "Nearest edge – averaging filter EAM approach".  The dialog box will close when the procedure is complete.  One or more outputs grids are placed in the current View.

### *Menu Item 2:  Calculate Animal Density and Total Population*

Any field in the attribute table of a habitat polygon shapefile or any other polygon shapefile can be used to summarize the animal density values in the density or margin of error grids.  Select the "Calculate Animal Density and Total Population" menu item (Figure 5) to choose an animal density or margin of error grid previously output by the model, a zone theme (polygon shapefile or grid), and an associated zone theme field over which to summarize the animal density data.  The animal density grid and zone theme must overlap geographically.  "No Data" cells in any zone (e.g., habitat class) are ignored in the calculation and a record is created accounting for them.

Click on the "Create density and population table" button and a table will appear with summary statistics of the animal density values for each zone in the zone field including: maximum, mean, minimum, range, standard deviation, sum, population, and total population.  The values in the "population" and "total population" fields are calculated assuming map units are in meters (Feet will be added in a future release.  Are there other units that you would like added?) and animal density function units are specified by the user (either indiv/100m2 or individuals/hectare). Are there other units that you would like added?). To open this file in Excel, export it as a dBase file (File-Export-dBase) or use Mike DeLaune's XTools ArcView extension available from ESRI's ArcScripts web page (http://gis.esri.com/arcscripts/scripts.cfm).  If there is a selection on the Zone Theme Field, then only selected features are used, otherwise, all features are used.  You can select records in the Zone Theme Field by either highlighting them with the selection tool in the current View or in the Zone Theme feature attribute table.

Figure 5. Calculate Animal Density and Total Population dialog box



## Menu Item 3:  Remove Noise

The remove noise menu item dialog (Figure 6) can be used to remove habitat patches in a grid theme that are smaller than a user-specified area or number of pixels.  It replaces these values with those of the patches' nearest neighbors.   The neighborhood used to determine the patch that any one pixel is in includes only orthogonal, and not diagonal, pixels.  It is intended to assist the user in removing habitat patches below the response threshold of the species modeled.  Different species will respond differently to edges at different scales.  For example, a raptor may not perceive an edge occurring over as short a distance as a songbird. The Remove Noise dialog can also be used to remove a habitat class entirely and replace the unclassified pixel values with those of the its nearest neighbors.

Figure 6. Remove Noise dialog box



# References

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# Trouble Shooting and Tips

***Entering formulas***

**Operator Precedence**

Avenue operator precedence is strictly left to right. In the following equation, x receives the value 24. With traditional precedence rules, the equation yields the value 14.

x = 5 + 3 * 3

Avenue evaluates parenthetic expressions first. With parentheses, the above equation can be modified to yield expected results (from ArcView GIS 3.2 documentation).

x = 5 + (3 * 3)

**Using Grids and Numbers Together**

When using a Number within Spatial Analyst requests, whether you use the Map Calculator or a Script Editor, you must convert it to a Grid object with the aNumb.AsGrid request in order for it to be used as a Grid. This is because Avenue requires that objects on either side of an operator, such as +, be of the same type. In this case, all objects involved are Grids.

newGrid = 8.AsGrid + theGrid

If you don't use aNumb.AsGrid, Avenue will interpret the 8 as a Number object, instead of adding a Grid object (where all cells have the value of 8) to another Grid object (theGrid). The one exception to this is when a Number follows the operator and the Grid precedes the operator. When a Grid object is seen first, followed by an operator the Spatial Analyst expects the operator to be followed by a Grid or Number. If it is a Number object it is assumed to be a Grid object and is automatically converted to a Grid object. So the following example works.

NewGrid = theGrid + 8

To be safe you should always use the aNumb.AsGrid request when you want a Number to be treated as a Grid object.

It is always safest to add .AsGrid after numerical values.  For example, ArcView will recognize the formula (4.1.AsGrid^dist)*3.AsGrid, but not (4.1^dist)*3.AsGrid. (from ArcView GIS 3.2 documentation).

You can use the "negate" request to make a value negative.  For example, 2.AsGrid.Negate*dist, although -2.AsGrid*dist also works.

An example functions that works:
2.AsGrid + 2.AsGrid/(1.AsGrid+(-2.AsGrid*(dist-2.AsGrid)).exp)

### Directory and file names
Spatial Analyst does not work properly when there are spaces in any directory names in the path where the grid resides or in the grid name itself.

### Segmentation violation
A "segmentation violation" error occasionally appears when running the "Find habitat edges" EAM function.  "Segmentation violation" errors are a common and frustrating class of errors well-known to many ArcView GIS users that can have many causes, some of which are difficult to track down.  We do not currently know the source of this error, as it relates to the use of the "Find habitat edges" EAM function, although ignoring it appears to make no difference in the model's performance.

### Frozen drop-down list
An ArcView GIS bug makes a drop down list freeze on screen - it stays on top even if you go to another application.  If you get a frozen drop down menu, go to another application, then come back to ArcView, and it will likely disappear.

### Map projections
A view's map projection can only be set if the map units of the spatial data it contains (or will contain) are decimal degrees (i.e., degrees of longitude-latitude expressed as a decimal rather than in degrees, minutes and seconds). This is because data in decimal degrees is in a spherical coordinate system and so is, by definition, unprojected. This data can therefore be drawn in any projection in ArcView. The map projection used by a view is set in the View Properties dialog box.

If your data is in decimal degrees and you set the Map units to decimal degrees but you choose not to set a projection, ArcView will draw the view by simply treating the longitude-latitude coordinates as unprojected spherical coordinates. This produces a map that looks the same as one that has been projected with the Plate Carree map projection, although its geometric characteristics are not the same.

Spatial data in other map units such as meters, is in a planar coordinate system and so is, by definition, already projected. This data either still reflects the projection of the source map it was digitized from, or has been transformed into a new map projection using ARC/INFO or another program.  When you use this data in ArcView, you can't choose a different map projection for it, and you shouldn't use the Projection button in the View Properties. If you know the map units of your data, then set the map units and distance units in the dialog box. Note that ArcView, at this release, does not support the transformation of data between different projection systems.

Instead, data that is not in decimal degrees is displayed using the projection system in which the data is currently stored.

Most, but not all, ARC/INFO coverages and grids contain an ASCII file called prj that describes the coordinate system used by that data set. You can look at this file to find out what projection your data is currently stored in.

When your spatial data is not in decimal degrees, and you are using data from a variety of different data sources on the same view, you should make sure that all these data sources are currently stored in the same map projection. If you draw data sources that are currently stored in different map projections on the same view you may get errors and inaccurate results. (Entire "Map Projections" section was taken directly from ArcView GIS 3.2 Help.)

### Slow performance

Limit the number of themes in any one View to about 15-20.  With more than 15-20 themes, the table of contents of a View becomes difficult to maneuver, the program slows down and may become unstable.

Use a local hard drive for the ArcView project working directory and move themes to a local drive.

### General solutions

It is sometimes possible to get rid of errors (e.g., "Segmentation Violation" errors) simply by saving the current ArcView project and reopening it.

**APPENDIX II:  Publications (1998-2003, chronologically)**

Meyer, C., T.D. Sisk, and W.W. Covington. 2001. *Microclimatic changes induced by ecological restoration of ponderosa pine forest in northern Arizona.* Restoration Ecology 9: 443-452.

Meyer, C. and T.D. Sisk. 2001. *Butterfly responses to microclimatic changes following ponderosa pine restoration.* Restoration Ecology, 9: 453-461.

Hampton, H. M., L. Ries, and T. D. Sisk. 2001. *A Spatial Model for Predicting Animal Responses to Ecological Changes.* Proceedings of Twenty-First Annual ESRI International User Conference. San Diego, California, USA

Sisk, T.D. and N.M. Haddad. 2002. *Incorporating the effects of habitat edges into landscape models: Effective area models for cross-boundary management.* Pages 208-240 in J. Liu and W. Taylor (eds.) Integrating Landscape Ecology into Natural Resource Management. Cambridge University Press, Cambridge.

Sisk, T.D., B.R. Noon, and H.M. Hampton. 2002. *Estimating the effective area of habitat patches in variable landscapes.* Pages 713-725, in: Scott, Michael J., Patricia Heglund, Michael L. Morrison, Jonathon B. Haufler, Martin G. Raphael, William A. Wall, and Fred B. Samson, eds. Predicting species occurrences: issues of accuracy and scale. Island Press: Washington.

Sisk, T.D. and J. Battin. 2002. Habitat edges and avian habitat: geographic patterns and insights for western landscapes. Studies in Avian Biology, 25: 30-48.

George, T. L., and L. A. Brand.  2002. *Fragmentation effects on birds in coast redwood forest*. Studies in Avian Biology, 25: 92-101. (Not Included)

Battin, J., and T. D. Sisk.  2003.  Assessing landscape-level influences of forest restoration on animal populations.  *In* P. Friederici and W. W. Covington, editors. Ecological restoration of southwestern ponderosa pine forests.  Island Press, Covelo, CA.

Ries, L., and W. F. Fagan. 2003. Habitat edges as a potential ecological trap for an insect predator. Ecological Entomology 28: 567-572.